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Nonlinear finite element analysis of composite bolted lap joints: experimental vs numerical tests

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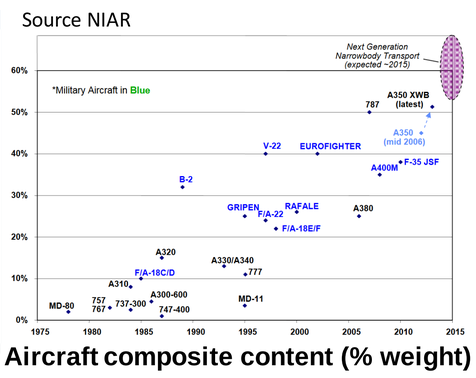
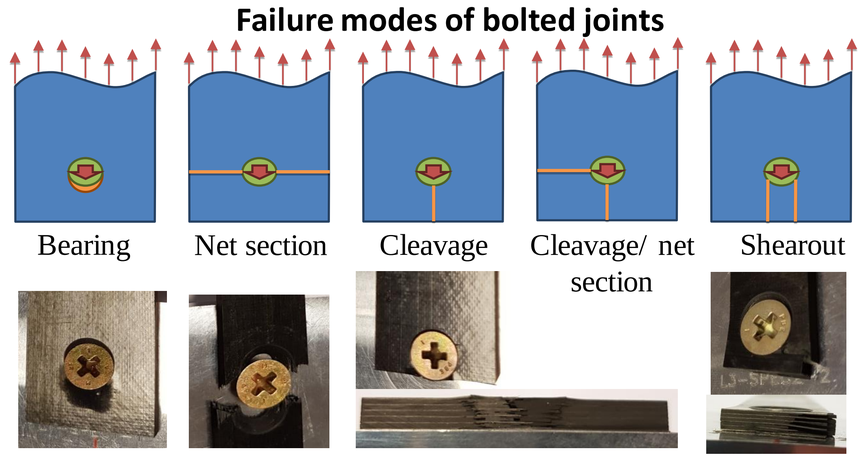
Introduction and context

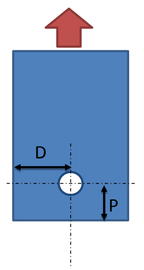


Aircraft composite content (% weight)

- Few composite parts on Falcon aircrafts
- Need to master composite bolted joint behavior to satisfy performance and safety requirements

Failure modes of bolted joints





Bearing = preferential failure mode for the design of bolted structures because of its progressive failure behavior

What are the physical phenomena leading to bearing failure of composite bolted joints ?

Nonlinear behavior of the composite material

Degrading mechanical properties

- In the different directions
- According to the load (tension, compression, etc.)

$$E_{11} = E_{11}^0(1-d_1)$$
$$E_{22} = E_{22}^0(1-d_2)(1-d_2^b)$$
$$G_{12} = G_{12}^0(1-d_4)(1-d_4^b)$$

Damage variables

- Correspond to the properties to degrade

$$d_1 = \phi_1 + \phi_2$$
$$d_2 = d_4 = \phi_4$$
$$d_2^b = d_4^b = \phi_4^b$$

Evolution laws and coupling

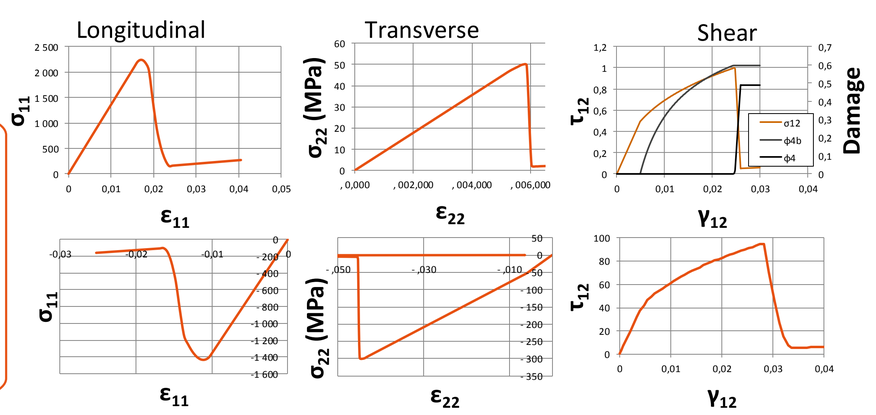
- Brittle failure or not
- Relation between physical phenomenon and properties to degrade ?

$$c_n = \max(\sqrt{f_n}, 1)$$
$$\phi_n = 1 - \exp\left(\frac{1-c_n^{m_n}}{m_n}\right)$$

Failure criteria

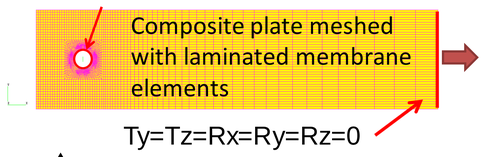
- At ply scale level
- One failure criterion f_i for one failure mode based on measured failure stresses

$$f_1 = \left(\frac{<\sigma_{11}>_+}{\sigma_{11}^{RT}}\right)^2 + \frac{\sigma_{12}^2+\sigma_{13}^2}{\sigma_{12}^{RS}} \qquad f_2 = \left(\frac{<-\sigma_{11}>_+}{\sigma_{11}^{RCC}}\right)^2$$
$$f_4 = \left(\frac{<\sigma_{22}>_+}{\sigma_{22}^{RT}}\right)^2 + \left(\frac{<-\sigma_{22}>_+}{\sigma_{22}^{RC}}\right)^2 + \left(\frac{\sigma_{12}}{\sigma_{12}^{R}}\right)^2$$
$$f_4^b = \left(\frac{<\sigma_{22}(1-d_2)>_+}{\sigma_{22}^{RT}}\right)^2 + \left(\frac{<-\sigma_{22}>_+}{\sigma_{22}^{RC}}\right)^2 + \left(\frac{\sigma_{12}(1-d_4)}{\sigma_{12}^{R}/k}\right)^2$$



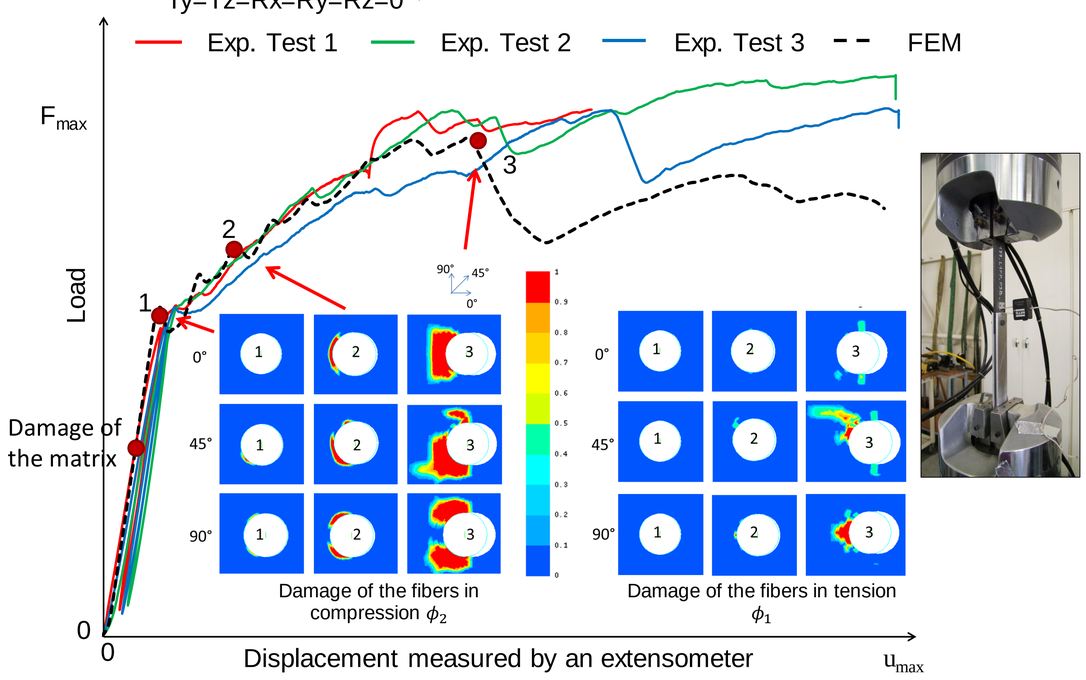
Double lap joint finite element model

Bolt modelled by contact elements
Master node linked to a fixed spring



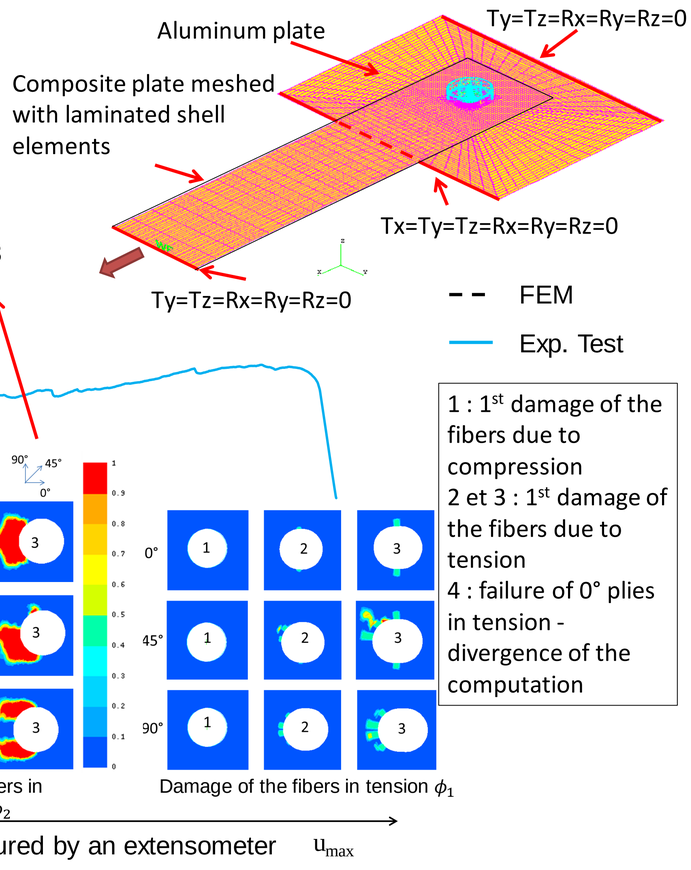
- Finite element models developped on SAMCEF® version 18.1

1 : 1st fibers damage due to compression
2 : 1st fibers damage due to tension
3 : tensile failure of 0° plies



Supported single lap joint finite element model

- Bolt modelled with contact elements – master nodes linked together by a beam with circular section in steel
- Initial stiffness higher than the experimental one



1 : 1st damage of the fibers due to compression
2 et 3 : 1st damage of the fibers due to tension
4 : failure of 0° plies in tension - divergence of the computation

Conclusions and perspectives

- Double lap joint finite element model: good correlation between numerical and experimental tests thanks to the non linear composite behavior law
- Supported single lap joint finite element model: differences between numerical and experimental stiffness, bolt modelling has to be improved because beam theory hypothesis not verified $\frac{L}{\phi} \sim 1$
- Bolt tightening not taken into account because of shell finite element modelling
- Damage scenarios quite similar between double lap joint and supported single lap joints
- Interrupted tests on single lap joint specimens : validation of the damage scenarios using DIC
- Volume finite element modelling : bolt tightening taken into account, better modelling of the contact between the plates and the fastener, better modelling of the bolt, inter laminar behavior could be studied